

North Pacific Acoustic Laboratory

A Collaborative Project Conducted by
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Long-Range Propagation

LONG-TERM GOALS

The ultimate limits of long-range sonar are imposed by ocean variability and the ambient sound field. Scattering from internal waves limits the temporal and spatial coherence of the received signal. Low-frequency noise is dominated by shipping and, ultimately, by wave-breaking processes. The resulting "granularity" of the noise field can be exploited for detection and localization purposes. Our ultimate objective is to understand the fundamental limits to signal processing imposed by these ocean processes, to enable advanced signal processing techniques, including matched field processing and other adaptive array processing methods, to capitalize on the three-dimensional character of the sound and noise fields.

OBJECTIVES

The objective of this research is to understand the basic physics of low-frequency, broadband propagation and the effects of environmental variability on signal stability and coherence. In particular, it focuses on 3-D wave front coherence (horizontal, vertical, and temporal), on the details of signal energy redistribution through mode scattering, on signal and noise variability on ocean-basin scales, and on environmental processes such as internal waves that most affect long-range coherence.

APPROACH

The North Pacific Acoustic Laboratory (NPAL) program takes advantage of the acoustic network installed by the Acoustic Thermometry of Ocean Climate (ATOC) program, as well as instrumentation developed for that network and data previously obtained using it. Existing network components include two low-frequency (75 Hz), broadband acoustic sources installed on Pioneer Seamount off central California and north of Kauai, 15 U. S. Navy SOSUS arrays instrumented to receive the source transmissions, and two autonomous vertical line arrays installed near Hawaii and Kiritimati Island from November-December 1995 to August-September 1996. NPAL will augment the existing network with a sparse billboard array at Sur Ridge off Point Sur, California, to receive the 3900-km-range transmissions from the Kauai source. The billboard array will be

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fabricated by reconfiguring largely existing VLA components developed for ATOC into five 700-m-long, 20-element vertical arrays, to allow measurement of the full 3-D signal wave front. The data previously collected by ATOC will be combined with data to be collected using the billboard array and the U. S. Navy SOSUS receivers:

- To study the temporal, vertical, and horizontal coherence of long-range, low-frequency resolved rays and modes and to compare the measurements to predictions.
- To study scattering/diffusion effects (mode scattering, steep ray scattering).
- To study horizontal multipathing.
- To study the effects of bottom interaction at the source.
- To measure directional ambient sound spectra and noise granularity.
- To improve basin-scale ocean nowcasts via assimilation of average temperature derived from acoustic travel-time data and of other data types into models.
- To determine environmental limitations on signal processing.

A CTD/XBT section is planned between the Kauai source and the billboard array to provide direct measurement of the sound speed field on the acoustic path.

This research is a joint effort involving B. Cornuelle, M. Dzieciuch, W. Munk, and P. Worcester at the Scripps Institution of Oceanography (SIO) and B. Dushaw, B. Howe, J. Mercer, and R. Spindel at the Applied Physics Laboratory (APL) of the University of Washington. We expect to collaborate in the analyses with A. Baggeroer (MIT), J. Colosi (WHOI), and S. Flatté (UCSC).

WORK COMPLETED

Operation of the Pioneer Seamount source and SOSUS receivers continued during FY97 with support from SERDP/DARPA and ONR until March 1997, when the Pioneer Seamount source cable was damaged. The acoustic network was subsequently repaired and upgraded, with the recovery, repair, and redeployment of the Kauai source in July 1997 (SERDP/DARPA funding), the replacement of the Kauai sea-shore interface cable with a newer one in better condition in September 1997 (joint SERDP/DARPA and ONR funding), and the repair of the Pioneer Seamount source cable in October 1997 (joint SERDP/DARPA, DOE/ONR, and ONR funding). The Pioneer and Kauai sources and the SOSUS receivers are now all operational for the first time. Modifications to the NMFS and other permits were obtained to allow the Pioneer Seamount and Kauai sources to operate for the full 24 months originally planned.

Preparations for the billboard array deployment were conducted in parallel. These preparations included upgrading and refurbishing existing VLA components (AVATOC electronics packages, pop-up data capsules, VLA cables, acoustic transponders, etc.) and fabricating additional equipment required (subsurface floats, additional pop-up data capsules, etc.). The billboard array deployment is now scheduled for July 1998, with recovery to occur in mid-1999. The CTD/XBT cruise is scheduled for August-September 1998, soon after the billboard array deployment.

Analyses of the existing ATOC AVLA and SOSUS array data continued throughout FY97.

RESULTS

Detailed comparisons between measured and predicted arrival patterns at 3252 km range for transmissions made during the ATOC Acoustic Engineering Test in late 1994 show that the early part of the arrival pattern consists of ray-like arrivals that are resolvable, identifiable, and stable (Worcester et al., 1997). The later part of the arrival pattern does not contain identifiable ray arrivals, due to scattering from internal-wave-induced sound-speed fluctuations. The ray travel times differ from predictions based on the sound-speed field constructed using nearly concurrent temperature and salinity measurements by more than *a priori* variability estimates, suggesting that the equation used to compute sound speed requires refinement. The trend in temperature over six days can be determined with an uncertainty of about 0.001°C/day (i.e., the total temperature change can be estimated with an uncertainty of about 0.010°C). For this acoustic path the sensitivity of the travel times to ocean variability is concentrated near the ocean surface (and at the corresponding conjugate depths), because all of the resolved ray arrivals have upper turning depths within a few hundred meters of the surface, except for the pulse termination. Surprisingly, for the identifiable timefronts observations of travel-time variance, average pulse shape, and the probability distribution function (PDF) of intensity suggest that the propagation is on the border of the unsaturated and partially saturated regimes (Colosi et al., 1997). After improving the specification of the ray weighting function, predictions of travel-time variance using the Garrett-Munk (GM) internal-wave spectrum at one-half the reference energy are in good agreement with the observations. Predictions of pulse spread, intensity PDFs and wave propagation regime are sensitive to the broadband characteristics of the transmitted pulse, but a simple model which takes into account broadband effects gives predictions which are in rough agreement with the observations.

Sea level variations along these paths are available for about 3 years from TOPEX/POSEIDON (T/P) altimeter measurements. Overlapping ATOC measurements for the Pioneer paths are now available for December 1995 to February 1997 when the source power cable was damaged. Analysis (Menemenlis et al., 1997; ATOC Consortium, 1997) reveals unexpected differences between ATOC-derived and T/P measured sea level variations that cannot be accounted for by the GCM models. The combination of T/P and ATOC promises to constitute a unique observational asset, far more powerful than either system used singly.

IMPACT/APPLICATIONS

This research has the potential to affect the design of long-range acoustic systems, whether for acoustic remote sensing of the ocean interior or for other applications. The data from ATOC indicate that existing systems do not begin to exploit the ultimate limits to acoustic coherence at long range in the ocean.

Estimates of basin-wide sound speed (temperature) fields obtained by the combination of acoustic, altimetric, and other data types with ocean general circulation models have the potential both to improve our understanding of gyre-scale ocean variability on seasonal and longer time scales and to improve our ability to make the acoustic predictions needed for matched field and other sophisticated signal processing techniques.

TRANSITIONS

None.

RELATED PROJECTS

- (i) NPAL exploits the acoustic network, instrumentation, and data of the Acoustic Thermometry of Ocean Climate (ATOC) program (P. I.s: P. Worcester and R. Spindel, SERDP/DARPA).
- (ii) NPAL will also exploit data obtained as part of the dual-frequency Alternate Source Test performed for the Ocean Acoustic Observatories' program to improve our understanding of the frequency dependence of horizontal coherence (P. I.s: Worcester, Mercer, and Spindel, ONR).
- (iii) Supplemental NPAL funding was provided by DARPA to enhance our research on the limits of exploiting coherent acoustic processing methods in the ocean, using data already collected by the ATOC program and data to be collected by the NPAL billboard array, as well as to help support our participation in the ad hoc Synergy Working Group meetings to explore possible collaboration between the NPAL program, the DARPA and ONR supported Full Field Program (FFP), and other related programs.
- (iv) A consortium led by R. Spindel was funded by the National Ocean Partnership Program (through ONR) to conduct research closely related to NPAL in response to a proposal entitled "Monitoring the North Pacific for Improved Ocean, Weather, and Climate Forecasts." Among other tasks, this program is developing an acoustic receiver to be installed on a surface mooring in the central North Pacific to record transmissions from the Pioneer Seamount and Kauai sources.
- (v) An integral part of NPAL involves studying the possible effects of low-frequency sound on marine mammals, for which support has been provided to C. Clark and W. Munk in response to a proposal entitled "Potential Effects of Low Frequency Sound on Distribution and Behavior of Marine Mammals" (SERDP/ONR). The Pioneer Seamount and Kauai sources are only permitted to transmit in conjunction with marine mammal research.

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Web addresses: <http://atoc.ucsd.edu/> (ATOC).